

Chemical abundance analysis of the old, rich open cluster Trumpler 20[★]

Giovanni Carraro^{★*}¹, Sandro Villanova², Lorenzo Monaco¹,
Giacomo Beccari¹, Javier A. Ahumada³, and Henri M.J. Boffin¹

¹ ESO, Alonso de Cordova 3107, 19001, Santiago de Chile, Chile
e-mail: gcarraro, lmonaco, gbeccari, hboffin@eso.org

² Departamento de Astronomia, Universidad de Concepción, Casilla 169, Concepción, Chile
e-mail: svillanova@astro-udec.cl

³ Observatorio Astronómico, Universidad Nacional de Córdoba, Laprida 854, 5000 Córdoba, Argentina
e-mail: javier@oac.uncor.edu

Received October 1, 2013; accepted October 16, 2013

ABSTRACT

Aims. Trumpler 20 is an open cluster located at low Galactic longitude, just beyond the great Carina spiral arm, and whose metallicity and fundamental parameters were very poorly known until now. As it is most likely a rare example of an old, rich open cluster – possibly a twin of NGC 7789 – it is useful to characterize it. To this end, we determine here the abundance of several elements and their ratios in a sample of stars in the clump of Trumpler 20.

Methods. We present high-resolution spectroscopy of eight clump stars. Based on their radial velocities, we identify six *bona fide* cluster members, and for five of them (the sixth being a fast rotator) we perform a detailed abundance analysis.

Results. We find that Trumpler 20 is slightly more metal-rich than the Sun, having $[\text{Fe}/\text{H}] = +0.09 \pm 0.10$. The abundance ratios of α -elements are generally solar. In line with recent studies of clusters as old as Trumpler 20, Ba is overabundant compared to the Sun. Our analysis of the iron-peak elements (Cr and Ni) does not reveal anything anomalous. Based on these results, we re-estimate the cluster age to be $1.5^{+0.2}_{-0.1}$ Gyr. Its distance to the Galactic centre turns out to be 7.3 kpc. With this distance and metallicity, Trumpler 20 fits fairly well in the metallicity gradient for the galactic inner disc.

Conclusions. With this new study, the characterization of Trumpler 20 is now on much more solid ground. Further studies should focus on the estimate of the binary fraction and on its main sequence membership.

Key words. stars: abundances - open clusters and associations: individual: Trumpler 20

1. Introduction

High-resolution spectroscopic data of stars in Galactic old open clusters are accumulating very rapidly. These star clusters are widely recognized as ideal tracers of the Galactic disc chemical and dynamical evolutions. A precise knowledge of the star cluster's abundance of the various chemical elements and their ratios allows us to investigate the assembly history of the thin disc, its relationship with the thick disc and the bulge, and the presence of sub-populations, which may be indicative of past accretion events (Friel 1995, Carraro et al. 2007, Magrini et al. 2009).

Rich old open clusters are particularly interesting, since the most important evolutionary phases are better represented in the colour-magnitude diagram, and allow better comparison with theoretical models of stellar evolution. Rich clusters are not very common among old open clusters, since the typical lifetime of a star cluster is around 200 Myr (Gieles et al. 2011). Typical examples are NGC 7789 (Gim et al. 1998) and NGC 2158 (Carraro et al. 2002).

A new member of this small family has recently been identified: Trumpler 20 (Platais et al. 2008, Seleznev et al. 2010a). This cluster possesses a conspicuous clump of He-burning stars, as do NGC 2158 and NGC 7789, but its main sequence (MS) is severely blurred by interlopers from the Galactic disc, and by some differential reddening (Platais et al. 2012). This is mostly because of its location just beyond the great Carina spiral arm, and its relatively low Galactic latitude ($l = 301.5^\circ, b = 2.2^\circ$). This has prevented a precise estimate of its age, since the location of the MS turnoff point (TO) is difficult to detect. Binary stars also play a crucial role (Carraro et al. 2010). The interest in Trumpler 20 lies mostly in its clump, as stressed by Carraro et al. (2010). Depending on its age, Trumpler 20 might actually be a twin of NGC 7789, and would therefore help to understand the details of the He-burning phases in the corresponding mass range (Girardi et al. 2000).

As described above, it has been quite difficult to estimate the cluster's parameters, especially its age. Platais et al. (2008) and Seleznev et al. (2010) first recognized the potential interest of Trumpler 20. Platais et al. (2008) concluded that the cluster is 1.3 Gyr old, metal poor ($[\text{Fe}/\text{H}] \sim -0.11$ dex), and at a distance of 3.3 kpc, adopting a reddening of $E(B - V) = 0.46$. Seleznev et al. (2010) confirmed this set of parameters, within the large uncertainties, by assuming solar abundances and V, I photometry. Later on, Carraro et al. (2010) provided a more detailed

* Based on observations collected at Paranal Observatory under program 088.D-0045

** On leave from the Dipartimento di Fisica e Astronomia, Università di Padova, Italy

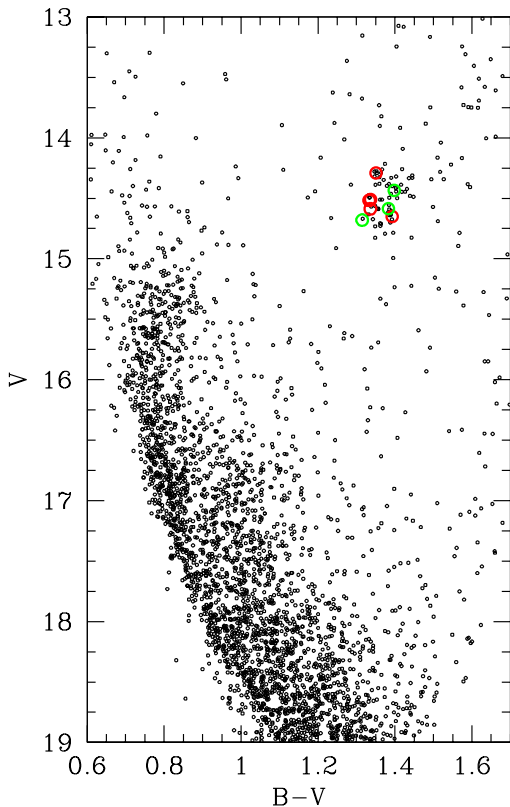


Fig. 1. V vs. $B - V$ colour-magnitude diagram of Trumpler 20 from Carraro et al. 2010. Red symbols indicate *bona fide* members.

study of Trumpler 20, based on $UBVI$ photometry. This study, which also assumed solar metallicity, revised the cluster parameters: the reddening value was found to be significantly smaller, $E(B - V) = 0.35$, the distance around 3 kpc, and the age around 1.4 Gyr.

Clearly, the lack of a precise metallicity estimate from high-resolution spectra limited the study of this cluster. The recent study by Platais et al. (2012) did not solve this problem. The study concentrated on the upper MS of the cluster in an attempt to clean the TO region by using medium-resolution spectra. The upper MS, once corrected for membership and differential reddening, is then fitted by using a $Z = 0.015$ isochrone, which implies the same set of parameters as in Platais et al. (2008), except for the reddening, which is closer to the Carraro et al. (2010) estimate.

In an attempt to improve the cluster characterization, in this paper we present the result of a high-resolution spectroscopic observational campaign aimed at determining the abundance of many elements for the stars in the red clump of Trumpler 20. The paper is organized as follows. In Section 2 we present the observational material and describe how radial velocities are derived. Section 3 is devoted to the abundance analysis, while in Section 4 we discuss in detail the results of the analysis. Section 5 summarizes our findings.

2. Observation and data reduction

Observations were taken in service mode on the nights of February 11 and March 3, 2012 using the multi-object fibre-fed FLAMES facility mounted at the ESO-VLT/UT2 telescope at the Paranal Observatory (Chile). Two 2400s exposures were taken simultaneously with the GIRAFFE medium-resolution spectrograph, and the red arm of the UVES high-resolution spectro-

graph. GIRAFFE was configured in Medusa mode in the setup HR08, which covers the wavelength range 4911–5163 Å at a resolution of $R=20,000$. The UVES spectrograph was, instead, set up around a 5800 Å central wavelength, thus covering the 4760–6840 Å wavelength range and providing a resolution of $R \approx 47,000$.

Here we discuss UVES data. UVES targets observed the probable red-clump targets, and are shown as open circles at the top of the cluster's V vs. $B - V$ colour-magnitude diagram in Fig. 1. In this figure red symbols indicate the five radial velocity members, and green the three stars for which abundance analysis was not done because they are non-members or fast rotator/binaries (see text for more details). Table 1 presents the target stars' IDs, coordinates, and B and V photometry from Carraro et al. (2010). The data were reduced using the ESO CPL based FLAMES-UVES pipeline version 5.0.9¹ for extracting the individual fiber spectra.

The spectra were eventually normalized using the standard IRAF task `continuum`. Radial velocities were computed using the IRAF/`fxcor` task to cross-correlate the observed spectra with a synthetic one from the Coelho et al. (2005) library with stellar parameters $T_{\text{eff}}=5250$ K, $\log g=2.5$, solar metallicity, and no α -enhancement. The IRAF `rvcorrect` task was used to calculate the correction from geocentric velocities to heliocentric. We took the star's radial velocity to be the average of the two epochs measured and the error to be the difference between the two values multiplied by 0.63 (small sample statistics; see Keeping 1962). For star 429 we report both measured values together with the formal `fxcor` uncertainties. The velocity difference between the two measurements (17.75 km s^{-1}) is significantly higher than the estimated errors and, therefore, the star may be in a binary system. Stars 429 and 496 are probably rotating faster than the other stars. The FWHM of the cross-correlation function is about 21 km s^{-1} and 33 km s^{-1} for the two stars, respectively, to be compared to an average for the other stars of $14.2 \pm 0.2 \text{ km s}^{-1}$.

We exclude stars 429 and 5309, which are non-radial velocity members, and using the non-parametric jackknife resampling method (Lupton 1993) we obtain for the cluster an average radial velocity of $\langle V_r \rangle = -40.9 \pm 1.2 \text{ km s}^{-1}$ with a dispersion $\sigma = 2.7 \pm 1.4 \text{ km s}^{-1}$.

Had we also excluded star 496, which is a fast rotator, we would have obtained $\langle V_r \rangle = -40.0 \pm 0.7 \text{ km s}^{-1}$, and $\sigma = 1.4 \pm 0.9 \text{ km s}^{-1}$.

These values are in good agreement with that measured by Platais et al (2008;2012), i.e. -40.8 and -40.6 km s^{-1} , respectively.

Finally, for the abundance analysis, the two epoch rest-frame spectra obtained for each star, were averaged together. The final spectra have signal-to-noise (SNR) ratios in the range 30-50 at $\sim 6070 \text{ Å}$.

3. Abundance analysis

The chemical abundances for Na, Mg, Al, Si, Ca, Ti, Cr, Fe, and Ni were obtained using the equivalent widths (EW method, as detailed in Marino et al. (2008). For C, N, O, Y, Ba, La, and Eu, whose lines are affected by blending, we used the spectrum-synthesis method. For this purpose we calculated five synthetic spectra having different abundances for the elements, and estimated the best-fitting value as the one that minimizes the *r.m.s.* scatter. Only lines not contaminated by telluric lines were used.

¹ <http://www.eso.org/sci/software/pipelines/>

Table 1. Red clump stars observed with UVES in the field of Trumpler 20. The two epoch radial velocities (RV) are listed together with their mean values.

ID	RA (J2000.0)	DEC (J2000.0)	V	B − V	RV (2012/02/12)	RV (2012/03/04)	<RV>
	hh:mm:ss.s	dd:mm:ss.s	mag	mag	(km s ^{−1})	(km s ^{−1})	(km s ^{−1})
80	12:40:11.4	−60:30:42.8	14.73	1.40	−38.01±1.17	−37.10±1.04	−37.56±0.57
207	12:39:55.6	−60:37:26.8	14.70	1.33	−39.69±1.30	−39.89±1.15	−39.79±0.13
258	12:39:17.5	−60:33:35.4	14.47	1.35	−41.13±1.45	−41.16±1.23	−41.14±0.02
429	12:40:01.2	−60:32:49.2	14.61	1.39	57.40±2.22	75.15±2.15	
496	12:39:37.7	−60:36:02.2	14.86	1.31	−46.67±4.57	−44.81±4.02	−45.74±1.17
542	12:39:12.0	−60:36:32.2	14.69	1.33	−40.85±1.25	−40.94±1.12	−40.90±0.06
609	12:39:40.0	−60:37:09.6	14.77	1.33	−40.38±1.22	−40.64±1.12	−40.52±0.17
5309	12:40:44.7	−60:37:32.0	14.77	1.37	11.53±1.21	11.07±1.17	11.30±0.29

Table 2. Atmospheric parameters from photometry (ph) and spectroscopy (sp).

ID	$T_{\text{eff,ph}}$	$\log g_{\text{ph}}$	$T_{\text{eff,sp}}$	$\log g_{\text{sp}}$	v_t	[Fe/H]	Comment
	K		K		(km s ^{−1})	dex	
80	4716	2.60	4970	2.55	1.11	0.09	
207	4847	2.73	4920	2.52	1.14	0.08	
258	4812	2.86	4910	2.50	1.18	0.06	
429	4730	2.65	4670	2.59	1.67	−0.41	non-member
496	4876	2.63					fast rotator
542	4840	2.76	4950	2.55	1.13	0.11	
609	4840	2.75	4970	2.60	1.10	0.10	
5309	4762	2.84	4650	2.75	0.80	0.08	non-member

Table 3. Individual abundances for Trumpler 20 members. Apart from iron, abundances are provided as [X/Fe], where X is the chemical species.

ID	C	N	O	CNO	Na	Mg	Al	Si	Ca	Ti
80	−0.20	0.04	−0.20	−0.17	0.20	−0.11	0.01	0.02	−0.06	−0.10
207	−0.18	0.04	−0.15	−0.14	0.22	−0.16	0.01	−0.01	−0.02	−0.06
258	−0.10	−0.08	−0.10	−0.10	0.20	0.00	0.08	0.02	0.02	−0.01
542	−0.21	0.00	−0.23	−0.20	0.21	−0.15	0.10	0.00	0.04	−0.01
609	−0.22	0.00	−0.23	−0.20	0.20	−0.09	0.08	0.00	0.00	

ID	V	Cr	[Fe/H]	Ni	Y	Zr	Ba	La	Eu
80	0.45	0.08	0.08	0.05	−0.16	0.10	0.19		−0.03
207	0.56	0.00	0.09	0.05	−0.17	0.05	0.19	−0.05	0.00
258	0.47	0.02	0.06	0.02		0.05	0.24	−0.04	−0.03
542	0.37	0.03	0.11	0.06	−0.09	0.04	0.13	−0.03	−0.07
609	0.39	0.05	0.10	0.02	−0.14	0.07	0.17	−0.01	−0.08

ATLAS9 (Kurucz 1970) model atmospheres were used for the methods: EW and spectrum-synthesis. The initial atmospheric parameters for the model atmosphere were assumed to be those typical for a RGB star of an open cluster, i.e. $T_{\text{eff}}=4500$ K, $\log g=2.5$, $v_t=1.20$ km/s, and [Fe/H]=0.0. We then refined them during the abundance analysis. As a first step, atmospheric models were calculated using ATLAS9 (Kurucz 1970) using the initial estimates of T_{eff} , $\log g$, v_t , and [Fe/H].

The value of T_{eff} , v_t , and $\log g$ were adjusted and new atmospheric models calculated in an interactive way in order to remove trends in excitation potential (EP) and equivalent width v_s abundance for T_{eff} and v_t , respectively, and to satisfy the ionization equilibrium for $\log g$. Fe I and Fe II were used for this purpose. The [Fe/H] value of the model was changed at each iteration according to the output of the abundance analysis. The local thermodynamic equilibrium (LTE) program MOOG (Snedden 1973) was used for the abundance analysis.

Typical internal errors are $\Delta(T_{\text{eff}})=50$ K, $\Delta \log g=0.2$ dex, $\Delta v_t=0.10$ km/s, and $\Delta[\text{Fe}/\text{H}]=0.05$ dex, respectively. To better

clarify the effect of atmospheric parameters on the derived abundance, we consider star 542, and show the effect on the final abundance of changes in the temperature, gravity, and micro-turbulence velocity. The results are shown in Table 5.

The line lists for the chemical analysis were obtained from many sources (Gratton et al. 2003, VALD & NIST²; McWilliam & Rich 1994; McWilliam 1998, SPECTRUM³, and SCAN⁴), and the $\log gf$ were calibrated using the solar-inverse technique and by the spectral synthesis method (see Villanova et al. 2009 for more details). For this purpose we used the high resolution, high S/N NAO solar spectrum (Kurucz et al. 1984). The solar abundances we obtained with our line list are reported in Table 4, together with those given by Grevesse & Sauval (1998) for comparison. We emphasize the fact that all the line-lists were calibrated on the Sun, including those used for the spectral synthesis. We provide it as a long table at the bottom of the

² <http://physics.nist.gov/PhysRefData/ASD/>

³ <http://www.phys.appstate.edu/spectrum/spectrum.html>

⁴ <http://www.astro.ku.dk/~uffegj/>

Table 4. Number of lines, and derived abundance σ . The value 9.999 indicates that σ was not computed.

ID	FeI	FeII	Na	Mg	Al	Si	Ca	TiI	TiII	V	Cr	Ni	Y
207	120/0.12	9/0.12	2/0.05	2/0.19	1/9.99	9/0.08	6/0.15	15/0.18	3/0.15	1/9.99	13/0.23	29/0.12	3/0.13
258	123/0.13	11/0.16	2/0.08	1/9.99	2/0.21	7/0.11	6/0.23	11/0.14	3/0.04	1/9.99	11/0.21	28/0.14	0/9.99
542	130/0.12	12/0.08	2/0.04	1/9.99	2/0.06	8/0.09	7/0.18	13/0.16	3/0.20	1/9.99	11/0.13	30/0.16	3/0.03
609	122/0.13	9/0.13	2/0.08	1/9.99	2/0.19	8/0.12	7/0.19	12/0.17	3/0.22	1/9.99	8/0.12	27/0.14	3/0.15
80	122/0.14	9/0.13	2/0.15	1/9.99	2/0.15	8/0.09	6/0.11	11/0.18	2/0.02	1/9.99	8/0.28	26/0.17	3/0.24
ID	C	N	O	Ba	Eu	La	Zr						
207	C2-band	CN-band	1/9.99	1/9.99	1/9.99	1/9.99	1/9.99						
258	C2-band	CN-band	1/9.99	1/9.99	1/9.99	1/9.99	1/9.99						
542	C2-band	CN-band	1/9.99	1/9.99	1/9.99	1/9.99	1/9.99						
609	C2-band	CN-band	1/9.99	1/9.99	1/9.99	1/9.99	1/9.99						
80	C2-band	CN-band	1/9.99	1/9.99	1/9.99	1/9.99	1/9.99						

Table 5. Error budget analysis. Under *El* the ratio $\Delta [X/Fe]$ is indicated, except for Fe, where $\Delta[Fe/H]$ is shown.

El.	$\Delta T=+50K$	$\Delta \log(g)=+0.20$	$\Delta vt=+0.10$
Fe	+0.03	+0.00	-0.07
FeII	-0.10	+0.09	-0.05
Na	+0.01	-0.03	+0.03
Mg	-0.01	-0.07	+0.00
Al	+0.01	-0.01	+0.05
Si	-0.05	0.02	+0.02
Ca	+0.07	0.03	+0.11
TiI	+0.04	-0.01	+0.03
TiII	-0.07	0.06	-0.04
V	+0.05	0.01	+0.02
Cr	+0.03	-0.01	+0.03
Ni	-0.01	0.03	+0.00
Y	-0.06	0.06	-0.04
C	-0.06	0.03	+0.04
N	+0.00	0.03	+0.06
O	-0.02	0.11	+0.04
Ba	-0.01	0.06	-0.03
Eu	-0.04	0.11	+0.05
La	-0.04	0.10	-0.01
Zr	-0.05	0.11	+0.0

paper. In addition, the C content was obtained from the C₂ system at 563.2 nm, and N from the CN lines at 634 nm.

Abundances for C, N, and O were determined all together in an interactive way in order to take into account any possible molecular coupling of these three elements. Our targets are objects evolved off the main sequence, so some evolutionary mixing is expected. This can affect the primordial C and N abundances separately, but not the total C+N+O content because these elements are transformed one into the other during the CNO cycle.

We are aware that we are deriving abundances for clump stars, but using the Sun as calibrator. Different approaches are adopted in the literature. Among the references we will use for comparison in the following, a similar approach was followed by Magrini et al. 2010, but not by Bensby et al. 2010. As a sanity check, we computed abundances for the giant star Arcturus using our line-list. Its atmospheric parameters are $T_{eff} = 4290^{\circ}K$, $\log g = 1.63$, and $vt = 1.29$ km/sec.

The results for individual elements are shown in Table. 6. One can readily see that the agreement with the literature is generally good. For instance, the differences with the recent work

Table 7. Adopted solar abundances

Element	This work	Grevesse & Sauval (1998)
Fe	7.50	7.50
C	8.49	8.52
N	7.95	7.92
O(6300)	8.80	8.83
Na	6.32	6.33
Mg	7.56	7.58
Al	6.48	6.47
Si	7.61	7.55
Ca	6.39	6.36
Ti	4.94	5.02
V	4.04	4.00
Cr	5.63	5.67
Ni	6.26	6.25
Y	2.25	2.24
Zr	2.56	2.60
Ba	2.34	2.13
La	1.26	1.17
Eu	0.52	0.51

by McWilliam et al. 2013 are below 0.2 dex. This is valid for all species except V, for which we obtain a significant difference that our value is 0.34 dex higher than the one in McWilliam et al. 2013. A correction of this size would bring the V abundance of the cluster to a value more similar to thin disc stars (see Fig. 3). It should be noticed, however, that the Arcturus literature abundances are quite scanty for this element. Other differences with McWilliam et al. 2013 are for Ti (0.13 dex), Y (0.1 7dex), and Ba (0.1 3dex). Our [Y/Fe] value is right in-between the McWilliam et al. 2013 and Peterson et al. 1993 values.

4. Discussion

In this section, we discuss in detail the outcome of the abundance analysis and its impact on the determination of the cluster parameters.

4.1. Metallicity

Metallicity is routinely estimated using the ratio [Fe/H]. The only previous estimate of Trumpler 20 metallicity from high-resolution spectroscopy is the Platais et al. (2008) one. The spectrum of a single giant (MG 675) is used to suggest for the whole cluster metal abundance. This star is not a clump star

Table 6. Individual abundances for Arcturus. Columns 5 to 10 indicate literature values from McWilliam et al. (2013, McW13), Ramirez and Allende Prieto (2011, Ra11), Fulbright et al. (2007, Fu07), Worley et al. (2009, W09), and Peterson et al. (1993, P93), respectively

El	X	Sun	[X/H]	[X/Fe]	McW13	Ra11	Fu07	W09	Pe93
C	7.885±0.005	8.49	-0.60	-0.10		+0.43			+0.0
N	7.79	7.95	-0.16	+0.34					+0.3
O	8.71	8.80	-0.09	+0.41	+0.46	+0.40	+0.48	+0.57	+0.4
Na	5.92	6.32	-0.26	+0.10	+0.09	+0.11	+0.09	+0.15	
Mg	7.513±0.005	7.56	-0.05	+0.45	+0.39	+0.37	+0.39	+0.34	
Al	6.304±0.023	6.48	-0.18	+0.32	+0.38	+0.34	+0.38	+0.25	
Si	7.408±0.004	7.61	-0.21	+0.29	+0.35	+0.33	+0.35	+0.20	
Ca	6.101±0.017	6.39	-0.29	+0.21	+0.21	+0.11	+0.21	+0.19	
Ti	4.83	4.94	-0.11	+0.39	+0.26	+0.27	+0.26	+0.35	
V	4.00±0.01	4.04	-0.04	+0.46	+0.12	+0.20			
Cr	5.175±0.010	5.63	-0.45	+0.05		-0.05			
Fe	7.00±0.01	7.50	-0.50		-0.49	-0.52		-0.61	
Ni	5.786±0.008	6.26	-0.49	+0.01		+0.06			
Y	1.697±0.003	2.25	-0.55	-0.05	-0.22			+0.12	
Ba	1.795±0.005	2.34	-0.54	-0.04	-0.17			-0.19	
Eu	0.32±0.05	0.52	-0.20	+0.30	+0.23			+0.36	

Table 8. Mean Trumpler 20 abundance ratios.

Abundance ratio	Mean	σ
<[C/Fe]>	-0.18±0.02	0.05±0.02
<[N/Fe]>	0.00±0.02	0.05±0.02
<[O/Fe]>	-0.18±0.03	0.06±0.02
<[CNO/Fe]>	-0.16±0.02	0.04±0.01
<[Na/Fe]>	0.21±0.00	0.01±0.00
<[Mg/Fe]>	-0.10±0.03	0.06±0.02
<[Al/Fe]>	0.06±0.02	0.04±0.01
<[Si/Fe]>	0.01±0.01	0.01±0.00
<[Ca/Fe]>	0.00±0.02	0.04±0.01
<[Ti/Fe]>	-0.03±0.02	0.04±0.01
<[α/Fe]>	-0.01±0.01	0.02±0.01
<[V/Fe]>	0.45±0.03	0.07±0.02
<[Cr/Fe]>	0.04±0.01	0.03±0.01
<[Fe/H]>	0.09±0.01	0.02±0.01
<[Ni/Fe]>	0.04±0.01	0.02±0.01
<[Y/Fe]>	-0.14±0.02	0.04±0.04
<[Zr/Fe]>	0.06±0.01	0.02±0.01
<[Ba/Fe]>	0.18±0.02	0.04±0.01
<[La/Fe]>	-0.03±0.01	0.02±0.01
<[Eu/Fe]>	-0.04±0.01	0.03±0.01

(see Platais et al. 2008, their Fig. 2), but most probably a bright red giant. The resulting value from these authors is $[\text{Fe}/\text{H}] = -0.11 \pm 0.13$, indicating that Trumpler 20 is slightly metal-poor with respect to the Sun, although the value is compatible with solar, within the uncertainty.

Our spectroscopic campaign focusses on the cluster red giant clump, one magnitude fainter, which we sample with eight stars (see Table 1). Six out of eight turn out to be *bona fide* radial velocity members. For all these stars, except for star 496, which is a fast rotator, we provide abundance analysis. We find an average $[\text{Fe}/\text{H}] = 0.09 \pm 0.01$, with no dispersion ($\sigma = 0.02 \pm 0.01$). In this case, however, 0.01 is simply the internal dispersion from the mean. Based on the analysis presented above (see Table 5), we derive a more reliable uncertainty of 0.074 when the errors on the atmospheric parameters are assumed as independent, or, in the opposite case, 0.095. We therefore adopt the value $[\text{Fe}/\text{H}] = 0.09 \pm 0.10$.

While, compatible with the Platais et al. (2008) figure, our result suggests that Trumpler 20 is slightly more metal-rich than the Sun. We will discuss later the implication of this result on the cluster parameters. This value of the metal abundance is not unexpected. Located well within the solar ring, Trumpler 20 is placed comfortably in the trend of abundance as a function of galactocentric distance. According to Magrini et al. (2009), the mean metallicity of old open clusters younger than ~ 4 Gyr is ~ 0.1 dex at the galactocentric distance of Trumpler 20 (~ 7 kpc).

4.2. α elements

Trumpler 20 is an intermediate-age open cluster located inside the solar circle. It is therefore interesting to compare its chemical properties with stars and star clusters located in the same region of the Milky Way. The comparison of α element abundance ratios (for Mg, Ca, Ti, and Si) with old open clusters and giant stars located in the inner disc is shown in Fig. 2. Giant stars from Bensby et al. (2010) are shown as grey circles, while the inner disc old open clusters NGC 6192, NGC 6404, and NGC 6583 from Magrini et al. (2010) are indicated as filled triangles. Our clump stars are shown as filled circles. The simultaneous inspection of this figure and Table 5 allows us to suggest that, overall, Trumpler 20 follows the trend of other inner disc indicators. In detail, $[\text{Ca}/\text{Fe}]$, $[\text{Ti}/\text{Fe}]$, and $[\text{Si}/\text{Fe}]$ follow giant stars of similar metallicity very closely, namely their abundance ratios are nearly solar. The only marginally deviating element is Mg, which for the same $[\text{Fe}/\text{H}]$, appears somewhat under-abundant, but still within the scatter. This also applies to the comparison with open clusters.

4.3. Iron peak elements

We compare two iron-peak element abundance ratios (Ni and Cr) with the literature values in Fig. 3. We could not compare V with thin and thick disc stars because the measure is based on a single line only, but this element ratio is clearly over-abundant with respect to stars of the same metallicity. Hyperfine structure (HFS) effects can be the culprit, as amply discussed in Pancino et al. (2010). Cr (lower panel) and Ni (upper panel), nicely compare with disc stars, although the Reddy et al. (2003, 2006) samples do not contain as many stars with similar metallicity as

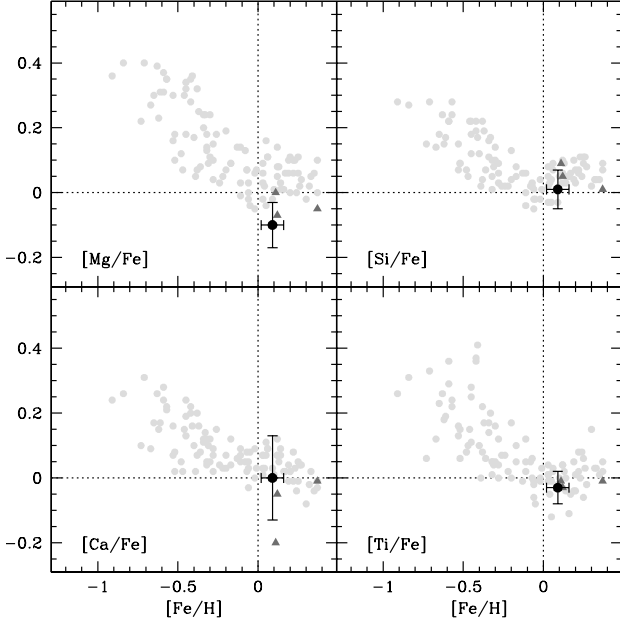


Fig. 2. Comparison between our α -element ratios (black solid dots) including error bars derived from Table 5, with data from old open clusters in the inner disc from Magrini et al. (2010; grey triangles) and inner disc giants from Bensby et al. (2010; light grey dots)

Trumpler 20. Besides, it is reassuring to note that for these two elements we find the same trend shown by the inner disc open cluster sample from Magrini et al. (2010, grey triangles).

4.4. Neutron capture elements

A recent review of neutron capture elements in intermediate age and old open clusters was presented by Mishenina et al. (2013), particularly for barium (Ba) and yttrium (Y). This study demonstrates that Ba is routinely over-abundant with respect to the Sun, while Y is either solar or under-abundant with respect to the Sun. In Fig. 4 we compare our findings (filled black circles) for Ba and Y with thin (Reddy et al. 2003, large light-grey filled circles) and thick disc stars (Reddy et al. 2006, small light-grey filled circles), and with open cluster data from Mishenina et al. (2013, grey triangles). From this figure one can readily realize that Trumpler 20 follows the general trend. The value of $[Ba/Fe]$ is marginally over-abundant (≈ 0.20), while Y is under-abundant. The same trend is visible in the sample of Pancino et al. (2010).

4.5. Revision of Trumpler 20 fundamental parameters

Carraro et al. (2010) derived the fundamental parameters of Trumpler 20, and adopted solar metallicity. With the spectroscopic estimate of the metallicity obtained in this work, we can now determine the fundamental parameters of the cluster more accurately.

The empirical metallicity $[Fe/H] = +0.09$ turns into the theoretical metallicity $Z=0.023$ (see e.g. Carraro et al. 1999). We generated isochrones⁵ from the Padova suite of models (Bressan et al. 2012) for this metallicity and different ages. The best fit was obtained for an age of 1.5 Gyr, as illustrated in

⁵ <http://stev.oapd.inaf.it/cgi-bin/cmd>

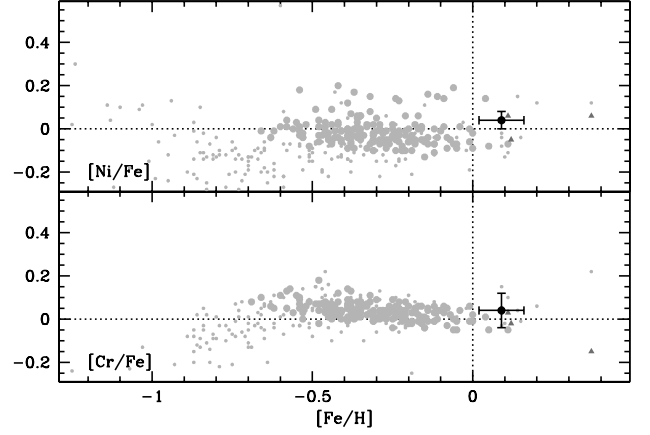


Fig. 3. Mean V (lower panel), Cr (middle panel), and Ni (upper panel) abundance ratios for Trumpler 20 giants (filled black circles), compared with thin disc stars (large light grey filled circles), thick disc stars (small light grey symbols), and inner disc open clusters (Magrini et al. 2010, grey triangles)

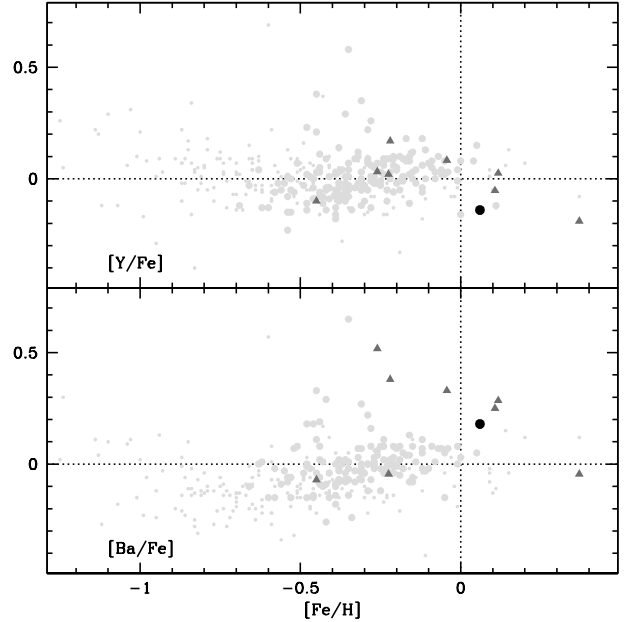


Fig. 4. Mean Ba (lower panel) and Y (upper panel) abundance ratios for Trumpler 20 giants (filled black circles), compared with thin disc stars (large light grey filled circles), thick disc stars (small light grey symbols), and intermediate-age and old open clusters (grey triangles)

Fig. 5, where we also display two additional isochrones (for 1.4 and 1.7 Gyr) to illustrate fitting uncertainties. The implied reddening is 0.34 ± 0.05 mag and the apparent distance modulus $m - M = 13.6 \pm 0.2$ mag, where uncertainties are inferred by moving the isochrones around the CMD. The fit of the turnoff

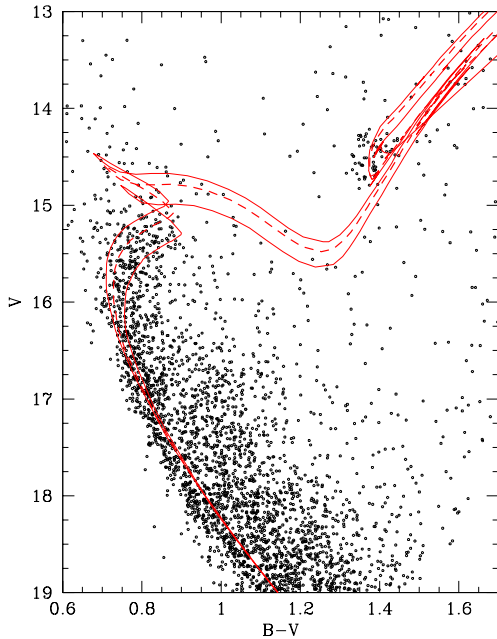


Fig. 5. Colour-magnitude diagram of Trumpler 20 from the photometric study of Carraro et al. (2010). Only stars within 6 arcmin from the cluster centre are considered. Over-imposed are three isochrones displaced using as reddening 0.34 mag and as apparent distance modulus 13.6 mag. The solid dashed isochrone is the best fit, for an age of 1.5 Gyr. To illustrate uncertainties in the age, we display two additional isochrones (solid red symbols) for an age of 1.4 and 1.7 Gyr. See text for details.

region is reasonable in spite of the heavy field star contamination and the presence of a significant fraction of binary stars (Carraro et al. 2010). As mentioned already in this last study, there is a marginal difficulty in matching the mean colour of the RGB clump. This is quite common in the literature (see, e.g., Carraro & Costa 2007) and can be ascribed to a variety of effects, the most important is probably related to the isochrone transformation from the theoretical to the empirical plane and, also, the calibration of the mixing length parameter.

Because wack any indication of abnormal absorption along the line of sight to Trumpler 20, we adopt $R_V = 3.1$, and derive a heliocentric distance of 3.2 kpc, slightly larger than the estimate of Carraro et al. (2010). If we adopt 8.5 kpc as the Sun distance to the Galactic centre, the galactic Cartesian coordinates for Trumpler 20 are: $X = 6.6$ kpc, $Y = -3.0$ kpc, and $Z = 120$ pc. As a consequence, the cluster distance to the Galactic Centre R_{GC} is 7.3 ± 0.3 kpc.

4.6. Trumpler 20 put into context

Magrini et al. (2010) studied the radial abundance gradient in the inner galactic disc, and concluded that the inner disc gradient (i.e. inside the solar circle) is steeper than the outer disc gradient. This evidence has been recently confirmed by the new analysis of APOGEE data by Frinchaboy et al. (2013). The addition of Trumpler 20 (see Fig. 6) confirms this piece of evidence. Located at 7.3 kpc from the Galactic centre and with a mean iron abundance $[Fe/H] = +0.09$, Trumpler 20 fits the trend defined by the other inner disc clusters. With the inclusion of Trumpler 20 the slope of the gradient is $d[Fe/H]/dR = -0.18 \pm 0.08$ dex/kpc. One interesting aspect to mention is that most inner disc clusters

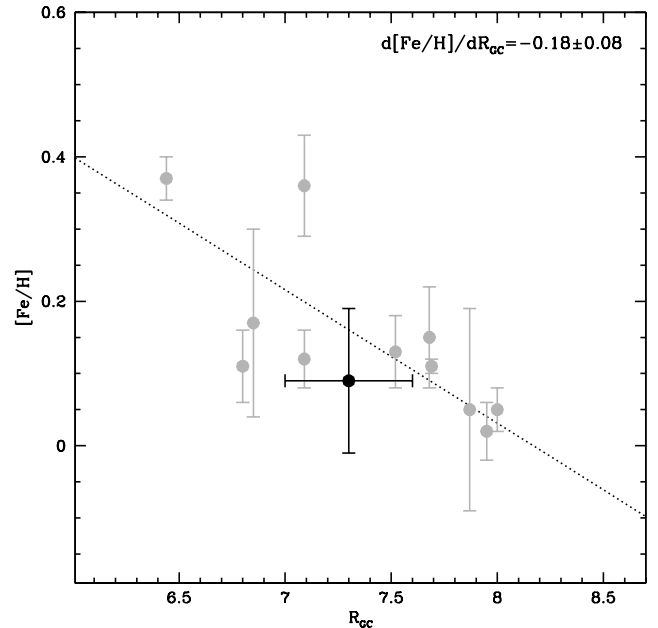


Fig. 6. The inner disc radial abundance gradient from Magrini et al. (2010; grey symbols) with the addition of Trumpler 20 (black circle). The dotted line is a weighted least square fit to the points, that yields -0.18 as value of the slope.

seem to preferentially locate in the fourth Galactic quadrant ($270 \leq l \leq 360$). In the sample of Magrini et al. (2010) only two clusters (NGC 6583 and NGC 6705) are located in the first Galactic quadrant. It would be interesting to extend the sample to more first quadrant clusters to search for abundance inhomogeneity or azimuthal gradients (Villanova et al. 2005; Lépine et al. 2011).

5. Conclusions

In this paper we have presented the first high-resolution spectroscopic study of a sample of red clump stars in the rich old open cluster, Trumpler 20. The new results fully support the findings in the previous photometric study by Carraro et al. (2010).

Our results can be summarized as follows:

- the cluster metallicity is mildly super-solar, with $[Fe/H] = +0.09 \pm 0.10$. We did not detect any significant spread among the five *bona fide* radial velocity members we were able to analyze;
- the abundance analysis reveals that Trumpler 20 is similar to other open clusters of the same age and metallicity as far as iron-peak and neutron-capture elements are concerned. The only deviation we found is for the α -element Mg, which is under-abundant with respect to the Sun. Its value is, however, consistent with the region covered by inner disc clusters or in inner disc giant stars of similar metallicity;
- we have revised the cluster fundamental parameters. The new values for reddening and distance modulus are 0.34 ± 0.05 mag and 13.6 ± 0.2 mag, respectively. By using these figures, we derive a cluster galacto-centric distance of 7.3 kpc;
- at this distance, and with a metallicity of $[Fe/H] = +0.09$, Trumpler 20 nicely matches the radial abundance gradient of the inner Galactic disc.

- we did not detect any spread in the Na abundances in our limited sample. More data would be required, however, to firmly discard the presence of multiple stellar populations in the cluster (Platais et al. 2012).

Further studies of this cluster should concentrate on estimating the binary fraction, and refining the shape of the main sequence via a detailed membership analysis. Quantifying the fraction of interlopers is an important step toward the determination of the cluster mass.

Acknowledgements. J. Ahumada is grateful to ESO for supporting his visit to the Santiago premises in 2011 and 2012, where this project started. S. Villanova gratefully acknowledges the support provided by FONDECYT N. 1130721.

References

- Bensby, T., Alves-Brito, A., Oey, M.S., Yong, D., Meléndez, J., 2010, *A&A*, 516, L13
- Bressan, A., Marigo, P., Girardi, L., et al. 2012, *MNRAS*, 427, 127
- Carraro, G., Girardi, L., Chiosi, C., 1999, *MNRAS*, 309, 430
- Carraro, G., Girardi, L., Marigo, P., 2002, *MNRAS*, 332, 705
- Carraro G., Costa E., 2007, *A&A*, 464, 573
- Carraro, G., Geisler, D.G., Villanova, S., FrinchX(oy, P.M., Majewski, S.R., , 2007, *A&A*, 476, 217
- Carraro, G., Costa, E., & Ahumada, J. A. 2010, *AJ*, 140, 954
- Coelho, P., Barbuy, B., Meléndez, J., Schiavon, R. P., & Castilho, B. V. 2005, *A&A*, 443, 735
- Friel, E.D., 1995, *ARA&A*, 33, 381
- FrinchX(oy, P.M., Thompson, B., Jackson K.M., O’Connell, J., et al., 2013, *ApJ*, 777, 1
- Fulbright, J.P., McWilliam, A., Rich, R.M., 2007, *ApJ*, 661, 1152
- Gieles, M., Heggie, D.C., Zhao, H., 2011, *MNRAS*, 413, 2509
- Gim, M., Vnadenberg, D.A., Stetson, P.B., Hesser, J.E., Zurek, D.R., 1998, *PASP*, 110, 1318
- Girardi, L., Mermillod, J.-C., Carraro, G., 2000, *A&A*, 354, 892
- Gratton, R. G., Carretta, E., Desidera, S., et al. 2003, *A&A*, 406, 131
- Grevesse, N., & Sauval, A. J. 1998, *SSRv*, 85, 161
- Keeping, E., S., 1962. *Introduction to Statistical Inference* (Princeton: van Nostrand)
- Kurucz, R. L., 1970, *SAO Special Report*, Cambridge: Smithsonian Astrophysical Observatory, 309
- Kurucz, R. L., Furenlid, I., Brault, J., & Testerman, L. 1984, *Solar flux atlas from 296 to 1300 nm*
- Lépine, J.R.D., Cruz, P., Scarano, S. Jr., et al., 2011, *MNRAS*, 417, 698
- Lupton, R., 1993, *Statistics in theory and Practice*, Princeton Un. Press
- Magrini, L., Sestito, P., Randich, S., Galli, D., 2009, *A&A*, 494, 95
- Magrini, L., Randich, S., Zoccali, M., Jilkova, L., Carraro, G., et al., 2010, *A&A*, 523, 11
- Marino, A.F., Villanova, S., Piotto, G., Milone, A.P., Momany, Y., Bedin, L.R. & Medling, A.M., 2008, *A&A*, 490, 625
- McWilliam, A., & Rich, R. M. 1994, *ApJS*, 91, 749
- McWilliam, A. 1998, *AJ*, 115, 1640
- McWilliam, A., Wallerstein, G., Mottini, M., 2013, *AJ*, in press, [arXiv:1309.2974](https://arxiv.org/abs/1309.2974)
- Mishenina, T., Korotin, S., Carraro, G., Kovtyukh, V.V., Yegorova, I.A., 2013, *MNRAS*, 433, 1436
- Monaco, L., Villanova, S., Moni Bidin, C., et al. 2011a, *A&A*, 529, A90
- Monaco, L., Saviane, I., Correnti, M., Bonifacio, P., & Geisler, D. 2011b, *A&A*, 525, A124
- Pancino, E., Carrera, R., Rossetti, E., Gallart, C., 2010, *A&A*, 511, A56
- Peterson, R., C., Dalle Ore, C.M., Kurucz, R.L., 1993, *ApJ*, 404, 333
- Platais, I., Melo, C., Fulbright, J. P., et al. 2008, *MNRAS*, 391, 1482
- Platais, I., Melo, C., Quinn, S. N., et al. 2012, *ApJ*, 751, L8
- Ramírez, I., Allende Prieto, C. 2011, *ApJ*, 743, 13
- Reddy, B.E., Tomkin, J., Lambert, D.L., Allende Prieto, C., 2003, *MNRAS*, 340, 304
- Reddy, B.E., Lambert, D.L., Allende Prieto, C., 2006, *MNRAS*, 367, 1329
- Seleznev, A., Carraro, G., Costa, E., Loktin, A., 2010, *New Astronomy*, 15, 61
- Smith, V.V., Suntzeff, N.B., Cunha, K., Gallino, R., Busso, M., Lambert, D.L., Straniero, O., 2000, *AJ*, 119, 1239
- Snedden, C. 1973, *ApJ*, 184, 839
- Villanova, S., Carraro, G., Bresolin, F., Patat, F., 2006, *AJ*, 130, 652
- Villanova, S., Carraro, G., & Saviane, I. 2009, *A&A*, 504, 845
- Villanova, S., & Geisler, D., 2011, *A&A*, 535, 31
- Worley, C.C., Cottrell, P.L., Freeman, K.C., Wylie-de Boer, E.C., 2000, *MNRAS*, 400, 1039

Table 9. Adopted line list, atomic parameters, equivalent widths (EW), and abundances (X).

λ	Element	χ	$\log(gf)$	EW	X	EW	X	EW	X	EW	X	EW	X
				207		258		542		609		80	
6154.219	11.0	2.100	-1.600	82.3	6.60	77.7	6.52	81.8	6.61	84.8	6.68	86.5	6.71
6160.742	11.0	2.104	-1.260	107.1	6.67	104.8	6.63	105.4	6.67	97.5	6.56	93.8	6.50
5711.083	12.0	4.340	-1.670	125.4	7.49	133.7	7.62	125.8	7.52	128.3	7.57	125.4	7.53
6318.702	12.0	5.110	-1.950	76.0	7.76	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
6696.014	13.0	3.140	-1.562	0.0	0.00	76.6	6.72	73.4	6.68	75.6	6.74	69.0	6.63
6698.663	13.0	3.140	-1.830	49.2	6.53	43.2	6.42	52.3	6.60	44.4	6.48	41.0	6.42
5517.529	14.0	5.082	-2.554	30.4	7.77	0.0	0.00	29.6	7.77	0.0	0.00	0.0	0.00
5645.603	14.0	4.930	-2.120	64.7	7.83	0.0	0.00	0.0	0.00	61.6	7.80	64.0	7.82
5684.479	14.0	4.930	-1.700	78.6	7.65	84.4	7.74	79.5	7.68	73.0	7.57	83.7	7.74
5690.419	14.0	4.930	-1.840	67.4	7.60	62.5	7.49	69.5	7.65	67.0	7.61	73.8	7.72
5701.098	14.0	4.930	-2.080	58.0	7.66	60.5	7.69	60.0	7.71	60.2	7.73	56.2	7.63
6125.014	14.0	5.610	-1.580	49.4	7.72	51.0	7.74	50.0	7.74	52.7	7.80	45.8	7.66
6142.481	14.0	5.619	-1.530	47.7	7.67	48.1	7.66	48.9	7.70	42.0	7.57	46.3	7.64
6145.010	14.0	5.610	-1.450	48.6	7.59	52.3	7.65	50.6	7.64	55.8	7.74	49.6	7.61
6244.465	14.0	5.616	-1.340	63.0	7.76	69.3	7.86	71.3	7.91	69.2	7.88	69.1	7.86
5260.377	20.0	2.520	-1.820	59.2	6.33	0.0	0.00	65.8	6.50	66.3	6.53	58.6	6.37
5349.458	20.0	2.709	-0.178	0.0	0.00	123.9	6.38	132.1	6.57	123.8	6.43	124.5	6.45
5867.554	20.0	2.930	-1.630	51.4	6.42	54.4	6.47	55.8	6.52	55.5	6.54	53.9	6.51
6161.287	20.0	2.523	-1.293	107.8	6.68	111.3	6.74	114.1	6.82	111.5	6.80	0.0	0.00
6166.429	20.0	2.521	-1.136	108.1	6.52	110.1	6.56	108.3	6.55	96.8	6.36	97.0	6.37
6455.593	20.0	2.520	-1.320	100.0	6.55	102.6	6.60	100.4	6.59	99.2	6.60	96.3	6.54
6572.774	20.0	0.000	-4.390	122.8	6.26	113.2	6.06	116.5	6.21	110.5	6.18	113.1	6.22
5062.094	22.0	2.160	-0.420	45.2	4.82	0.0	0.00	56.7	5.07	0.0	0.00	43.5	4.85
5113.437	22.0	1.440	-0.820	0.0	0.00	71.5	4.92	0.0	0.00	0.0	0.00	0.0	0.00
5145.457	22.0	1.460	-0.600	83.0	5.00	85.5	5.04	76.3	4.88	84.6	5.12	80.7	5.02
5282.413	22.0	1.053	-1.640	60.6	5.01	65.0	5.09	66.3	5.17	68.4	5.25	69.0	5.27
5295.774	22.0	1.050	-1.680	53.3	4.91	0.0	0.00	0.0	0.00	52.1	4.96	55.1	5.02
5490.144	22.0	1.460	-0.950	65.1	4.88	68.0	4.93	64.5	4.91	67.8	5.01	0.0	0.00
5648.560	22.0	2.495	-0.350	35.6	4.91	0.0	0.00	0.0	0.00	36.8	4.99	0.0	0.00
5739.465	22.0	2.249	-0.724	30.3	4.89	37.4	5.02	33.7	4.99	0.0	0.00	0.0	0.00
5922.105	22.0	1.050	-1.450	78.6	5.10	73.7	4.99	75.8	5.09	75.0	5.11	73.0	5.06
5965.822	22.0	1.870	-0.540	71.7	5.05	69.5	4.99	71.9	5.09	79.9	5.29	72.5	5.14
6091.167	22.0	2.270	-0.430	55.2	5.07	53.5	5.03	49.5	5.00	0.0	0.00	0.0	0.00
6126.214	22.0	1.070	-1.360	82.0	5.07	82.7	5.07	78.9	5.06	76.3	5.04	71.6	4.94
6258.098	22.0	1.440	-0.340	103.1	4.93	99.1	4.84	104.7	5.01	98.7	4.93	95.2	4.85
6261.094	22.0	1.430	-0.440	124.6	5.47	121.5	5.39	123.3	5.48	118.0	5.42	114.1	5.34
6554.220	22.0	1.440	-1.210	77.1	5.22	0.0	0.00	77.2	5.26	76.6	5.30	70.7	5.18
5211.523	22.1	2.590	-1.456	63.1	5.07	60.8	4.99	66.8	5.19	0.0	0.00	0.0	0.00
5336.783	22.1	1.582	-1.600	104.2	4.90	108.5	4.96	105.9	4.96	98.0	4.83	96.5	4.77
5418.762	22.1	1.580	-2.080	75.6	4.78	83.6	4.92	75.3	4.80	73.2	4.78	73.0	4.74
5490.688	22.1	1.566	-2.730	0.0	0.00	0.0	0.00	0.0	0.00	61.6	5.19	0.0	0.00
5670.847	23.0	1.081	-0.578	94.0	4.65	89.1	4.53	84.4	4.47	82.8	4.48	84.6	4.52
4801.021	24.0	3.120	-0.140	73.3	5.53	76.0	5.60	85.6	5.86	0.0	0.00	0.0	0.00
4936.335	24.0	3.113	-0.280	77.2	5.77	61.6	5.38	72.3	5.67	79.4	5.90	72.4	5.71
4964.923	24.0	0.940	-2.490	89.4	5.68	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
5214.125	24.0	3.369	-0.753	0.0	0.00	42.1	5.69	41.6	5.71	0.0	0.00	0.0	0.00
5238.954	24.0	2.710	-1.410	48.5	5.73	54.1	5.83	0.0	0.00	43.2	5.66	0.0	0.00

Table 9. Adopted line list, atomic parameters, equivalent widths (EW), and abundances (X) .

λ	Element	χ	log (gf)	EW	X	EW	X	EW	X	EW	X	EW	X
				207		258		542		609		80	
5247.564	24.0	0.961	-1.550	121.0	5.44	138.5	5.79	126.9	5.61	0.0	0.00	124.8	5.61
5271.993	24.0	3.449	-0.482	58.5	5.86	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
5287.170	24.0	3.438	-0.957	34.1	5.80	0.0	0.00	40.9	5.97	39.2	5.95	31.6	5.78
5296.691	24.0	0.983	-1.310	132.2	5.44	142.8	5.63	140.8	5.65	137.3	5.62	136.2	5.60
5300.743	24.0	0.980	-2.120	112.6	5.82	106.8	5.68	113.7	5.89	108.2	5.81	106.0	5.76
5304.173	24.0	3.460	-0.730	0.0	0.00	38.6	5.69	0.0	0.00	44.5	5.85	0.0	0.00
5318.764	24.0	3.440	-0.720	42.1	5.73	0.0	0.00	49.0	5.90	0.0	0.00	0.0	0.00
5329.137	24.0	2.914	-0.194	120.0	6.30	115.2	6.22	0.0	0.00	0.0	0.00	125.8	6.47
5348.315	24.0	1.004	-1.140	142.1	5.46	147.6	5.55	147.5	5.59	148.5	5.65	146.1	5.61
5628.635	24.0	3.420	-0.790	0.0	0.00	0.0	0.00	43.8	5.82	0.0	0.00	0.0	0.00
6330.086	24.0	0.940	-2.880	92.3	5.82	91.1	5.79	88.3	5.79	85.4	5.77	83.3	5.73
5058.490	26.0	3.642	-2.750	0.0	0.00	0.0	0.00	0.0	0.00	39.9	7.61	40.3	7.61
5141.737	26.0	2.424	-2.124	0.0	0.00	126.5	7.55	117.9	7.42	0.0	0.00	129.6	7.69
5180.060	26.0	4.473	-1.120	77.9	7.74	0.0	0.00	80.0	7.81	0.0	0.00	76.1	7.73
5196.056	26.0	4.256	-0.590	99.9	7.52	109.2	7.73	107.3	7.71	104.2	7.68	104.7	7.68
5197.934	26.0	4.301	-1.480	63.5	7.56	73.7	7.80	71.9	7.78	67.3	7.70	77.1	7.93
5217.385	26.0	3.211	-1.020	0.0	0.00	0.0	0.00	0.0	0.00	139.5	7.46	0.0	0.00
5223.177	26.0	3.635	-2.243	59.2	7.47	64.2	7.56	69.0	7.72	62.3	7.59	66.0	7.68
5225.525	26.0	0.110	-4.669	137.7	7.52	151.6	7.75	154.7	7.87	0.0	0.00	133.8	7.54
5242.488	26.0	3.634	-0.807	0.0	0.00	115.2	7.40	114.4	7.41	0.0	0.00	117.5	7.50
5243.771	26.0	4.256	-0.930	79.1	7.33	90.6	7.61	0.0	0.00	93.8	7.74	78.7	7.37
5247.048	26.0	0.087	-4.800	0.0	0.00	128.4	7.39	135.0	7.61	134.7	7.66	0.0	0.00
5253.015	26.0	2.279	-3.849	0.0	0.00	70.9	7.72	62.9	7.59	61.2	7.59	56.3	7.46
5253.459	26.0	3.283	-1.523	0.0	0.00	104.0	7.36	105.2	7.43	102.2	7.39	111.2	7.57
5288.524	26.0	3.694	-1.550	98.0	7.81	92.9	7.67	95.1	7.77	84.3	7.53	88.3	7.62
5294.540	26.0	3.640	-2.680	43.7	7.56	41.7	7.50	46.9	7.65	34.9	7.41	0.0	0.00
5295.310	26.0	4.415	-1.530	0.0	0.00	54.4	7.51	47.4	7.39	53.3	7.54	51.2	7.48
5321.105	26.0	4.434	-1.261	72.5	7.69	75.4	7.76	66.1	7.57	60.8	7.47	61.2	7.47
5326.140	26.0	3.573	-2.210	79.2	7.84	70.7	7.61	67.1	7.56	0.0	0.00	71.4	7.69
5386.327	26.0	4.154	-1.700	63.7	7.60	54.0	7.37	58.2	7.50	0.0	0.00	51.0	7.35
5401.260	26.0	4.320	-1.720	63.7	7.81	56.0	7.62	64.6	7.85	54.9	7.65	0.0	0.00
5441.333	26.0	4.312	-1.590	63.2	7.66	50.7	7.37	56.9	7.54	56.8	7.56	56.6	7.54
5460.870	26.0	3.071	-3.530	29.0	7.43	26.7	7.36	31.3	7.50	35.4	7.61	28.8	7.46
5461.543	26.0	4.445	-1.612	55.7	7.65	49.6	7.51	58.0	7.73	58.1	7.75	47.0	7.49
5464.275	26.0	4.143	-1.582	76.6	7.76	79.5	7.82	80.8	7.88	0.0	0.00	72.2	7.70
5470.086	26.0	4.446	-1.610	55.2	7.64	53.6	7.59	52.0	7.59	46.6	7.49	50.0	7.56
5494.458	26.0	4.070	-1.960	60.7	7.70	64.4	7.77	0.0	0.00	64.4	7.84	55.5	7.62
5522.444	26.0	4.210	-1.400	78.5	7.70	66.5	7.40	68.8	7.50	76.5	7.70	73.2	7.61
5525.540	26.0	4.230	-1.184	76.7	7.47	85.1	7.66	78.9	7.55	83.5	7.69	78.9	7.57
5538.512	26.0	4.218	-1.559	64.7	7.54	72.7	7.72	65.6	7.59	68.5	7.69	77.0	7.88
5539.276	26.0	3.640	-2.610	42.0	7.43	47.5	7.54	50.1	7.63	44.3	7.53	50.2	7.65
5546.503	26.0	4.371	-1.080	0.0	0.00	83.9	7.68	80.0	7.62	82.9	7.72	86.8	7.80
5552.685	26.0	4.950	-1.800	0.0	0.00	0.0	0.00	19.1	7.57	0.0	0.00	0.0	0.00
5560.208	26.0	4.430	-1.000	72.4	7.40	65.4	7.23	76.9	7.53	70.0	7.40	73.2	7.47
5576.087	26.0	3.430	-0.840	0.0	0.00	149.2	7.52	140.9	7.44	136.4	7.40	135.2	7.39
5577.018	26.0	5.030	-1.520	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	43.6	7.98
5587.568	26.0	4.140	-1.650	73.8	7.76	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
5608.969	26.0	4.210	-2.360	0.0	0.00	33.1	7.63	36.4	7.73	25.2	7.49	30.5	7.61
5611.351	26.0	3.630	-2.960	37.8	7.68	36.6	7.64	33.0	7.60	0.0	0.00	31.6	7.59
5618.627	26.0	4.210	-1.260	84.7	7.70	68.6	7.31	81.5	7.65	79.4	7.63	72.4	7.45
5619.594	26.0	4.390	-1.480	71.5	7.81	65.1	7.65	67.0	7.73	65.9	7.73	62.5	7.64
5635.816	26.0	4.260	-1.560	55.3	7.37	55.9	7.37	57.9	7.45	62.7	7.58	56.2	7.42
5636.695	26.0	3.640	-2.530	45.0	7.41	53.4	7.57	47.7	7.49	45.1	7.46	0.0	0.00
5638.255	26.0	4.220	-0.690	105.3	7.59	97.3	7.41	109.8	7.71	112.0	7.77	102.8	7.58
5649.981	26.0	5.100	-0.750	0.0	0.00	59.1	7.59	0.0	0.00	0.0	0.00	0.0	0.00
5651.462	26.0	4.470	-1.780	35.9	7.41	42.5	7.55	40.0	7.52	37.9	7.49	38.4	7.50
5652.312	26.0	4.260	-1.760	53.5	7.53	59.0	7.64	55.4	7.60	54.4	7.60	50.6	7.51
5677.681	26.0	4.100	-2.680	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	27.9	7.74
5679.019	26.0	4.652	-0.680	81.4	7.51	79.0	7.46	81.4	7.54	78.5	7.50	77.3	7.46
5680.234	26.0	4.190	-2.370	31.4	7.58	38.5	7.73	35.6	7.70	32.3	7.64	0.0	0.00
5701.542	26.0	2.560	-2.130	135.7	7.75	136.8	7.75	130.7	7.69	131.2	7.74	134.8	7.80

Table 9. Adopted line list, atomic parameters, equivalent widths (EW), and abundances (X).

λ	Element	χ_i	$\log(gf)$	EW	X	EW	X	EW	X	EW	X	EW	X
				207		258		542		609		80	
5705.460	26.0	4.301	-1.455	67.1	7.58	72.4	7.68	69.5	7.65	74.4	7.80	70.6	7.70
5717.827	26.0	4.280	-0.990	96.8	7.76	96.8	7.76	98.0	7.81	92.1	7.71	97.4	7.82
5731.758	26.0	4.260	-1.060	84.3	7.53	90.7	7.67	88.1	7.65	0.0	0.00	82.0	7.52
5741.844	26.0	4.260	-1.640	59.8	7.54	0.0	0.00	61.3	7.60	58.1	7.56	63.1	7.66
5742.953	26.0	4.180	-2.320	38.0	7.66	0.0	0.00	46.3	7.86	43.4	7.82	0.0	0.00
5752.028	26.0	4.549	-0.867	83.3	7.61	73.2	7.39	86.0	7.70	76.3	7.51	72.4	7.41
5753.120	26.0	4.260	-0.588	100.0	7.40	107.9	7.57	107.4	7.58	99.2	7.44	103.6	7.52
5760.342	26.0	3.640	-2.450	60.0	7.64	0.0	0.00	54.7	7.55	63.2	7.77	47.4	7.41
5775.076	26.0	4.220	-1.040	84.4	7.46	91.5	7.60	0.0	0.00	87.5	7.58	0.0	0.00
5853.147	26.0	1.480	-5.170	0.0	0.00	0.0	0.00	48.0	7.59	53.6	7.73	51.3	7.68
5855.076	26.0	4.610	-1.540	43.7	7.49	44.1	7.49	51.2	7.67	50.2	7.67	46.8	7.58
5856.086	26.0	4.290	-1.550	62.5	7.55	72.8	7.78	65.8	7.65	72.5	7.84	66.0	7.67
5859.583	26.0	4.549	-0.388	94.7	7.41	98.1	7.48	99.8	7.55	96.1	7.50	93.0	7.42
5861.101	26.0	4.280	-2.400	0.0	0.00	25.7	7.56	30.2	7.70	22.3	7.52	29.8	7.70
5862.353	26.0	4.549	-0.148	102.6	7.34	103.0	7.35	106.0	7.43	107.2	7.48	99.7	7.32
5881.273	26.0	4.610	-1.770	41.4	7.67	38.1	7.59	0.0	0.00	0.0	0.00	0.0	0.00
5905.668	26.0	4.650	-0.700	85.7	7.62	84.8	7.59	79.3	7.50	75.1	7.43	82.2	7.58
5916.246	26.0	2.453	-2.857	0.0	0.00	112.2	7.80	106.8	7.74	0.0	0.00	89.1	7.35
5927.785	26.0	4.650	-1.020	66.6	7.51	63.1	7.42	66.0	7.51	60.9	7.42	66.6	7.54
5929.672	26.0	4.550	-1.170	69.4	7.60	73.2	7.68	72.2	7.69	66.8	7.60	70.5	7.67
5930.179	26.0	4.650	-0.010	112.7	7.46	120.1	7.59	117.8	7.57	108.9	7.43	112.8	7.50
5934.652	26.0	3.928	-1.060	104.1	7.51	103.6	7.50	102.7	7.51	99.6	7.48	107.8	7.63
5956.693	26.0	0.860	-4.500	114.3	7.53	112.7	7.47	113.0	7.55	109.2	7.52	116.0	7.66
5983.675	26.0	4.549	-0.558	97.3	7.62	91.3	7.48	92.8	7.54	94.7	7.61	0.0	0.00
6003.010	26.0	3.880	-0.970	108.3	7.45	108.6	7.46	110.7	7.53	107.0	7.48	106.7	7.47
6007.958	26.0	4.650	-0.620	89.8	7.64	0.0	0.00	90.6	7.68	86.1	7.61	85.0	7.57
6008.555	26.0	3.880	-0.830	121.2	7.55	110.5	7.36	113.3	7.44	106.9	7.35	110.3	7.41
6024.055	26.0	4.548	0.200	125.8	7.37	123.3	7.33	134.0	7.51	124.9	7.40	119.1	7.30
6027.049	26.0	4.070	-1.020	91.5	7.41	94.2	7.46	89.5	7.39	93.6	7.52	98.2	7.61
6056.001	26.0	4.730	-0.340	90.6	7.44	93.0	7.48	92.0	7.49	89.4	7.46	87.5	7.41
6065.482	26.0	2.610	-1.400	0.0	0.00	165.9	7.42	167.9	7.48	165.9	7.48	163.3	7.45
6079.004	26.0	4.650	-0.960	71.3	7.54	71.9	7.55	71.4	7.57	62.1	7.38	69.3	7.53
6082.706	26.0	2.220	-3.550	92.7	7.74	88.9	7.64	0.0	0.00	0.0	0.00	79.6	7.51
6093.639	26.0	4.610	-1.340	55.2	7.52	61.6	7.66	54.6	7.53	50.3	7.46	56.3	7.58
6094.367	26.0	4.650	-1.610	46.7	7.66	44.1	7.59	47.7	7.70	42.7	7.61	42.2	7.59
6096.661	26.0	3.980	-1.810	73.2	7.65	67.1	7.51	72.6	7.66	70.9	7.66	67.8	7.58
6098.240	26.0	4.560	-1.800	0.0	0.00	39.4	7.58	39.2	7.61	43.7	7.72	0.0	0.00
6120.244	26.0	0.910	-5.930	40.3	7.45	43.3	7.48	0.0	0.00	0.0	0.00	39.4	7.50
6127.902	26.0	4.143	-1.349	86.6	7.71	80.1	7.55	77.6	7.53	86.7	7.78	81.9	7.65
6151.613	26.0	2.180	-3.230	99.3	7.51	95.2	7.40	95.5	7.47	96.6	7.54	90.7	7.39
6157.723	26.0	4.070	-1.120	99.6	7.67	0.0	0.00	107.7	7.87	96.8	7.67	95.9	7.64
6159.369	26.0	4.607	-1.890	33.4	7.60	34.3	7.61	38.6	7.73	29.1	7.53	28.4	7.51
6165.355	26.0	4.140	-1.430	78.9	7.60	79.5	7.61	78.6	7.63	76.7	7.62	73.1	7.52
6173.331	26.0	2.220	-2.800	120.5	7.61	122.7	7.64	118.0	7.60	117.4	7.63	116.4	7.60
6187.394	26.0	2.830	-4.190	32.4	7.83	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
6187.985	26.0	3.940	-1.660	89.2	7.79	83.3	7.65	87.0	7.77	85.1	7.76	72.5	7.47
6200.311	26.0	2.610	-2.300	118.7	7.53	117.6	7.49	120.3	7.60	116.8	7.57	117.0	7.57
6213.427	26.0	2.220	-2.450	138.4	7.60	125.4	7.34	138.1	7.64	127.5	7.48	129.0	7.50
6219.279	26.0	2.200	-2.340	148.5	7.64	143.5	7.55	144.6	7.62	138.4	7.55	143.7	7.63
6220.776	26.0	3.880	-2.370	55.5	7.70	0.0	0.00	53.6	7.69	52.0	7.68	0.0	0.00
6226.729	26.0	3.880	-2.110	59.2	7.52	59.0	7.50	59.0	7.54	52.3	7.43	56.1	7.49
6232.638	26.0	3.650	-1.180	116.1	7.51	120.1	7.58	124.5	7.69	122.3	7.68	107.2	7.40
6240.643	26.0	2.220	-3.230	103.8	7.65	96.3	7.47	98.0	7.56	93.9	7.52	101.1	7.67
6246.315	26.0	3.602	-0.778	144.5	7.49	142.4	7.46	147.6	7.56	144.3	7.53	142.3	7.51

Table 9. Adopted line list, atomic parameters, equivalent widths (EW), and abundances (X)

λ	Element	χ	$\log(gf)$	EW	X	EW	X	EW	X	EW	X	EW	X
				207		258		542		609		80	
6252.556	26.0	2.400	-1.640	171.7	7.46	162.2	7.34	0.0	0.00	0.0	0.00	0.0	0.00
6265.131	26.0	2.180	-2.460	146.1	7.69	146.1	7.68	152.9	7.84	148.4	7.81	143.8	7.72
6270.221	26.0	2.860	-2.510	98.5	7.59	106.7	7.76	100.6	7.67	100.4	7.71	102.3	7.74
6271.272	26.0	3.332	-2.763	66.6	7.68	59.3	7.52	64.6	7.67	0.0	0.00	66.0	7.72
6297.789	26.0	2.220	-2.660	132.2	7.68	123.4	7.49	126.8	7.61	124.0	7.60	122.9	7.57
6302.492	26.0	3.686	-1.083	118.4	7.52	110.1	7.35	0.0	0.00	115.5	7.52	110.7	7.42
6311.494	26.0	2.830	-3.150	0.0	0.00	0.0	0.00	0.0	0.00	75.8	7.74	0.0	0.00
6315.814	26.0	4.070	-1.650	74.3	7.62	70.4	7.52	79.6	7.77	70.8	7.60	74.2	7.66
6322.684	26.0	2.590	-2.330	112.4	7.37	120.4	7.53	118.4	7.54	111.2	7.43	105.0	7.28
6330.842	26.0	4.730	-1.170	63.1	7.65	0.0	0.00	55.2	7.50	0.0	0.00	54.6	7.49
6335.327	26.0	2.200	-2.200	151.7	7.53	156.2	7.59	150.0	7.54	145.4	7.51	152.6	7.61
6336.821	26.0	3.686	-0.806	144.4	7.59	138.9	7.52	138.4	7.54	139.2	7.57	141.6	7.60
6380.738	26.0	4.190	-1.280	86.0	7.62	89.1	7.68	85.8	7.65	90.4	7.78	0.0	0.00
6392.533	26.0	2.280	-3.956	64.4	7.56	65.4	7.57	56.4	7.44	55.0	7.44	0.0	0.00
6416.918	26.0	4.795	-0.995	57.0	7.40	55.2	7.36	53.2	7.34	55.4	7.41	51.4	7.32
6430.844	26.0	2.176	-1.996	177.6	7.62	0.0	0.00	0.0	0.00	0.0	0.00	173.5	7.64
6436.399	26.0	4.190	-2.410	38.2	7.74	32.6	7.60	0.0	0.00	34.9	7.71	37.4	7.75
6464.664	26.0	0.958	-5.511	61.3	7.44	56.9	7.34	56.0	7.39	55.3	7.42	54.7	7.40
6481.868	26.0	2.280	-2.890	121.5	7.71	124.9	7.77	111.1	7.54	117.9	7.73	113.7	7.63
6496.460	26.0	4.795	-0.520	0.0	0.00	93.8	7.71	95.6	7.78	95.4	7.80	0.0	0.00
6498.935	26.0	0.960	-4.600	125.1	7.85	0.0	0.00	120.5	7.80	0.0	0.00	0.0	0.00
6518.363	26.0	2.830	-2.520	0.0	0.00	0.0	0.00	99.3	7.57	108.6	7.82	110.9	7.86
6533.925	26.0	4.560	-1.220	75.5	7.75	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
6556.783	26.0	4.795	-1.705	0.0	0.00	33.3	7.60	37.0	7.71	36.5	7.72	0.0	0.00
6569.212	26.0	4.733	-0.330	0.0	0.00	109.5	7.75	110.4	7.79	108.7	7.79	105.5	7.72
6574.222	26.0	0.990	-4.970	94.9	7.59	92.6	7.52	96.1	7.66	90.4	7.60	89.3	7.56
6581.203	26.0	1.480	-4.750	0.0	0.00	82.1	7.69	86.4	7.85	0.0	0.00	0.0	0.00
6591.304	26.0	4.590	-2.030	0.0	0.00	0.0	0.00	31.9	7.69	0.0	0.00	32.6	7.71
6593.870	26.0	2.430	-2.300	139.9	7.63	139.7	7.62	137.6	7.63	140.1	7.72	143.2	7.76
6608.020	26.0	2.280	-3.990	61.8	7.53	67.1	7.61	59.9	7.52	61.1	7.58	55.0	7.45
6625.014	26.0	1.010	-5.330	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	88.3	7.91
6627.537	26.0	4.550	-1.500	60.4	7.69	58.0	7.63	58.4	7.67	59.3	7.72	65.7	7.84
6633.406	26.0	4.835	-1.260	0.0	0.00	0.0	0.00	0.0	0.00	61.9	7.85	56.6	7.73
6633.743	26.0	4.560	-0.700	0.0	0.00	102.4	7.78	98.3	7.72	91.9	7.62	97.6	7.72
6699.132	26.0	4.590	-2.170	22.6	7.58	0.0	0.00	27.0	7.71	19.1	7.51	0.0	0.00
6703.563	26.0	2.760	-3.010	90.5	7.72	92.3	7.74	85.9	7.65	81.0	7.59	78.8	7.53
6713.736	26.0	4.790	-1.440	45.0	7.58	0.0	0.00	43.5	7.57	40.8	7.52	0.0	0.00
6725.352	26.0	4.100	-2.220	42.8	7.52	45.2	7.55	40.8	7.50	46.8	7.64	44.7	7.59
6726.662	26.0	4.610	-1.010	72.5	7.51	73.9	7.53	68.6	7.45	72.9	7.57	66.8	7.43
6733.145	26.0	4.640	-1.440	55.1	7.62	0.0	0.00	54.0	7.62	58.5	7.73	47.3	7.48
6739.516	26.0	1.557	-4.934	62.7	7.60	58.9	7.50	57.1	7.53	0.0	0.00	58.6	7.59
6745.951	26.0	4.070	-2.730	0.0	0.00	0.0	0.00	25.1	7.63	0.0	0.00	0.0	0.00
6750.149	26.0	2.420	-2.510	133.1	7.67	128.0	7.56	126.4	7.58	124.4	7.59	127.4	7.64
6752.700	26.0	4.638	-1.244	0.0	0.00	71.6	7.76	0.0	0.00	74.2	7.87	0.0	0.00
6786.853	26.0	4.190	-1.920	57.3	7.61	58.6	7.63	54.9	7.59	54.6	7.60	52.0	7.54
6793.251	26.0	4.070	-2.420	44.1	7.71	0.0	0.00	37.8	7.61	35.4	7.57	0.0	0.00
6806.839	26.0	2.730	-3.110	87.5	7.70	87.8	7.69	89.1	7.77	81.3	7.64	82.9	7.67
6810.256	26.0	4.610	-0.970	80.5	7.64	70.4	7.42	74.5	7.53	77.6	7.63	68.4	7.42
5197.570	26.1	3.230	-2.230	102.2	7.63	102.9	7.62	104.9	7.71	0.0	0.00	108.1	7.76
5234.623	26.1	3.221	-2.180	97.2	7.45	103.6	7.57	103.3	7.61	102.7	7.62	0.0	0.00
5264.800	26.1	3.230	-3.130	0.0	0.00	60.0	7.41	61.7	7.50	0.0	0.00	0.0	0.00
5325.550	26.1	3.221	-3.210	0.0	0.00	54.2	7.33	63.3	7.61	65.5	7.70	65.1	7.64
5425.245	26.1	3.199	-3.290	68.3	7.78	65.8	7.68	61.9	7.63	70.3	7.88	67.2	7.74
5991.366	26.1	3.150	-3.590	53.8	7.64	59.0	7.74	57.0	7.74	50.3	7.59	44.5	7.40
6084.096	26.1	3.200	-3.800	38.5	7.53	53.0	7.85	36.7	7.49	0.0	0.00	42.1	7.60
6149.239	26.1	3.890	-2.750	47.9	7.48	0.0	0.00	50.5	7.56	49.5	7.56	46.8	7.43
6247.557	26.1	3.870	-2.350	62.0	7.42	66.6	7.50	73.0	7.70	64.4	7.51	73.7	7.69

Table 9. Adopted line list, atomic parameters, equivalent widths (EW), and abundances (X)

λ	Element	χ	$\log(gf)$	EW	X	EW	X	EW	X	EW	X	EW	X
				207		258		542		609		80	
6369.453	26.1	2.890	-4.180	0.0	0.00	32.7	7.38	40.3	7.62	36.7	7.55	0.0	0.00
6432.675	26.1	2.890	-3.630	66.1	7.67	57.4	7.43	61.9	7.59	54.2	7.43	59.1	7.49
6456.379	26.1	3.900	-2.080	80.8	7.62	79.3	7.56	81.1	7.64	77.5	7.58	78.3	7.55
4935.825	28.0	3.941	-0.350	73.6	6.12	65.7	5.91	70.3	6.06	64.9	5.95	75.8	6.21
5010.930	28.0	3.635	-0.870	76.8	6.36	79.3	6.42	74.9	6.34	74.8	6.37	0.0	0.00
5094.403	28.0	3.830	-1.090	54.5	6.25	55.1	6.25	53.3	6.24	52.1	6.23	42.9	6.01
5102.960	28.0	1.676	-2.810	95.6	6.51	95.7	6.50	94.4	6.52	87.6	6.38	0.0	0.00
5155.120	28.0	3.898	-0.640	78.4	6.45	69.7	6.22	78.8	6.49	0.0	0.00	0.0	0.00
5197.155	28.0	3.898	-1.240	59.6	6.59	0.0	0.00	70.4	6.87	0.0	0.00	0.0	0.00
5468.100	28.0	3.850	-1.630	36.3	6.38	0.0	0.00	36.4	6.40	31.3	6.30	0.0	0.00
5578.716	28.0	1.676	-2.790	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	89.0	6.27
5589.353	28.0	3.898	-1.200	54.1	6.39	49.5	6.27	55.5	6.44	0.0	0.00	53.4	6.40
5748.347	28.0	1.680	-3.280	78.3	6.40	71.5	6.22	74.5	6.35	74.4	6.39	83.6	6.60
5760.826	28.0	4.100	-0.780	65.1	6.43	64.7	6.41	65.8	6.48	61.8	6.41	56.5	6.27
5996.724	28.0	4.230	-1.040	0.0	0.00	46.4	6.40	46.3	6.43	42.9	6.37	40.5	6.31
6007.306	28.0	1.676	-3.364	74.6	6.36	72.4	6.29	66.7	6.23	65.9	6.24	64.1	6.18
6086.274	28.0	4.260	-0.470	69.6	6.39	71.0	6.41	73.7	6.51	69.9	6.45	69.9	6.43
6108.112	28.0	1.680	-2.470	116.3	6.41	114.3	6.35	111.5	6.35	113.0	6.43	114.9	6.45
6111.067	28.0	4.090	-0.800	65.1	6.41	55.6	6.19	61.2	6.35	58.5	6.31	60.6	6.34
6128.972	28.0	1.680	-3.330	84.4	6.54	78.9	6.39	80.4	6.49	79.9	6.52	78.3	6.46
6130.129	28.0	4.260	-0.930	51.9	6.45	47.1	6.33	48.0	6.39	40.9	6.25	38.4	6.18
6176.806	28.0	4.090	-0.210	92.5	6.44	92.3	6.43	89.3	6.39	97.3	6.59	92.5	6.47
6177.240	28.0	1.830	-3.540	53.0	6.25	54.9	6.27	53.3	6.29	49.8	6.25	57.6	6.39
6204.599	28.0	4.090	-1.110	47.3	6.33	48.6	6.34	53.5	6.49	47.8	6.38	42.9	6.26
6223.979	28.0	4.100	-0.950	55.0	6.35	49.7	6.22	53.6	6.34	52.9	6.35	57.4	6.43
6322.161	28.0	4.150	-1.220	39.8	6.34	41.4	6.36	45.7	6.49	39.9	6.38	37.3	6.31
6327.596	28.0	1.680	-3.100	99.9	6.62	97.2	6.54	93.0	6.51	92.3	6.54	98.9	6.67
6378.246	28.0	4.150	-0.830	63.2	6.46	52.9	6.22	64.1	6.50	60.4	6.44	60.3	6.42
6482.795	28.0	1.930	-2.830	101.9	6.68	100.9	6.64	107.8	6.85	98.1	6.69	100.0	6.71
6586.306	28.0	1.950	-2.800	89.5	6.38	90.3	6.38	96.3	6.57	92.8	6.54	93.0	6.52
6598.594	28.0	4.230	-0.940	48.2	6.32	50.0	6.34	52.0	6.42	51.0	6.42	48.9	6.36
6635.117	28.0	4.420	-0.770	49.7	6.40	52.8	6.45	54.0	6.51	51.9	6.48	56.8	6.58
6767.769	28.0	1.830	-1.960	128.5	6.21	131.3	6.25	130.6	6.29	125.8	6.25	133.3	6.37
6772.311	28.0	3.660	-0.930	83.6	6.39	89.1	6.49	86.1	6.47	77.2	6.31	94.2	6.65